Dynamic Wireless Charging for E-Vehicles

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Keywords: Dynamic Wireless Charging, Inductive Power Transfer, Electric Vehicles (EVs), Battery Management System (BMS), Power Conversion System, Sustainable Mobility, High-Frequency Magnetic Field.

Abstract: Dynamic wireless charging for electric vehicles (EVs) which would allow an EV to constantly recharge while moving, as iron coils embedded in roadway infrastructure would further charge traveling vehicles through induction. The coils create a high-frequency magnetic field that is picked up by the receiving coils in the EV to create a charging current for the battery. The power conversion system includes MOSFETs, ultrafast diodes (UF5408), PWM controllers (SG3525, U3525), and utilizes an AC-to-DC converter in an efficient manner. And a Battery Management System (BMS) makes sure the EV is doing its best to charge, while sensors and control algorithms adjust how much power is transferred around here in real time depending on where the EV is at. This technology not only dramatically enhances the range of EVs, eliminating the need for frequent charging stops, but also supports sustainable urban mobility by reducing reliance on fixed charging infrastructure.

1 INTRODUCTION

In the march towards a more sustainable form of transport, the transition to electric vehicles (EVs) is a fundamental pillar. But traditional plug-in charging methods have serious drawbacks, potentially long stationary periods and extensive charging stations. Dynamic Wireless Charging (DWC) helps mitigate these issues since it provides ongoing power transfer, while the vehicles are on the go, so it helps in eliminating charging stops, extend the driving range, providing more convenience. This invention marks an essential breakthrough in the evolution of modern transport, paving the way for an electric mobility revolution and a carbon-neutral future.

This system using a billing and alignment system in the EVs to maximize energy transfer and reduce the loss of power. The system measures costs required for power and promotes a billing that is accurate with data to the end-user. The alignment system uses proximity sensors to ensure that the inductive coils are optimally aligned during charging, maximising power transfer efficiency and reducing energy losses. Although DWC promises considerable potential, infrastructure development, efficiency and cost effectiveness remain significant challenges. But steady developments in technology and its implementation within a concise framework makes DWC one of the most futuristic forms of sustainable mobility.

2 RELATED WORKS

The technology behind Dynamic Wireless Charging (DWC) for Electric Vehicles (EVs) has become increasing interesting for every full-size car manufacturer, as it solves one of the biggest hassles with EVs being the downtime for charging, the amount of travelled distance and offers a sustainable way for mobility. This phase gives a summary of modern research and improvements in wi-fi electricity circulate (WPT) for EVs, with a focal point on key demanding situations along with alignment precision, electricity switch performance, billing mechanisms, and infrastructure hurdles in particular in Indian context.

2.1 Principles of Wireless Power Transfer (WPT)

The idea of wi-fi power switch (WPT) goes back to Nikola Tesla's experiments with electromagnetic induction. But with modern EV charging, the

R., K., S., A., A. J., A. and M., B.
Dynamic Wireless Charging for E-Vehicles.
DOI: 10.5220/0013889600004919

In *Proceedings of the 1st International Conference on Research and Development in Information, Communication, and Computing Technologies (ICRDICCT'25 2025) - Volume 2*, pages 760-766
ISBN: 978-989-758-777-1

principle is quite a bit similar. MIT (2007) delivered the idea of WiTricity, demonstrating mid-variety resonant inductive power transfer, which considerably advanced strength transfer performance. The SAE J2954 Standard (2016) set international recommendations for stationary wi-fi EV charging, paving the manner for studies into dynamic charging. While stationary wireless charging is now commercially available, dynamic charging is still in its experimental section, with subject trials evaluating its real-international feasibility.

2.2 Real-World Applications of Dynamic Wireless Charging

2.2.1 KAIST's On-Line Electric Vehicle (OLEV) System

One of the primary actual-global demonstrations of dynamic inductive charging changed into the OLEV machine, advanced via the Korea Advanced Institute of Science and Technology (KAIST) in 2013. Key findings from their trials encompass: Achieved 85% energy transfer performance with a coil hole of 20 cm. Successfully applied in public delivery buses in South Korea.

2.2.2 Qualcomm Halo System

Demonstrated wi-fi power switch at 20 kW while automobiles had been in motion. Successfully tested on French highways at speeds of up to 100 km/h.

2.2.3 Electron Wireless Road Trials

Conducted huge-scale checks in Sweden and Israel (2021) by using embedding inductive charging coils into roads.

Focused on public delivery and freight vehicles, proving scalability for business use.

These trials demonstrate that DWC is possible for urban and highway programs, however power transfer inefficiencies and high infrastructure prices continue to be huge demanding situations.

2.3 Challenges in the Effectiveness of Power Transfer

2.3.1 Coil Misalignment and Power Loss

For dynamic charging to be effective, the receiver coil in the EV must stay aligned with the road-embedded transmitter coils. However, several challenges affect efficiency:

- Lateral misalignment can cause a 30–50% drop in power transfer efficiency.
- Variable vehicle speeds make it difficult to maintain optimal energy transfer.
- Inductive coupling limitations reduce efficiency when the coil gap exceeds 10–20 cm.

2.3.2 Alignment Solutions

To solve these challenges, scientists have discovered: Infrared (IR) sensor to regulate the current flow depending on the exact location of the vehicle. Automatic orbit key system to secure any match with charging zones. Electromagnetic guidance mechanisms to optimize coil placements.

2.4 Smart Billing Systems for Dynamic Charging

2.4.1 The Need for Real-Time Billing

Unlike plug-in charging stations, dynamic charging requires real-time energy tracking to ensure fair and accurate billing. Several models have been proposed:

- RFID-based billing: Identifies the vehicle and processes transactions automatically.
- IoT-based metering: Uses cloud-connected sensors to monitor power usage in real time.
- Blockchain-based payment models: Provide secure and transparent energy transactions.

2.4.2 Applications in Smart Cities

- Japan's wireless toll collection systems could be adapted for seamless DWC billing.
- European pilots have tested vehicle-to-grid (V2G) communication, allowing dynamic tracking of energy consumption.

For DWC to be commercially viable, such billing mechanisms are essential.

2.5 Challenges and Opportunities for India

Despite global progress, India has yet to conduct large-scale DWC trials. Key challenges include:

- Infrastructure limitations: Most Indian roads and highways lack the strength for embedding charging coils.

- High costs: The upfront investment for inductive charging infrastructure is significant.
- Grid limitations: India's energy grid needs to be upgraded to support widespread wireless power transfer.

Potential Implementation in India

Given India's push for EV adoption, DWC could be introduced in key areas:

1. Smart Cities:
   - EV-friendly cities like Delhi, Bengaluru, and Hyderabad could integrate DWC lanes in select zones.
2. Highway Corridors:
   - Wireless charging infrastructure could be implemented on major expressways, such as the Delhi-Mumbai Expressway and Bengaluru-Chennai Corridor.
3. Urban Public Transport:
4. wireless charging zones at bus stops and taxi stands could improve the efficiency of public transport.
5. Key considerations in scaling DWC in India will be public-private partnerships, policy incentives, and technology improvements in battery and grid.

3 METHODOLOGY (PROOF OF CONCEPT)

3.1 System Design and Architecture

This paper describes a proof-of-concept (PoC) for a dynamic wireless charging system that demonstrates a high efficiency and is particularly suitable for electric vehicles (EVs). It addresses critical challenges in implementing dynamic wireless charging (DWC) such as power transfer efficiency, alignment precision, and real-time billing.

It has a 12V DC input for a wireless power transfer system powered by a high-frequency inverter at its core. A half-bridge inverter/final amplifier is used, using IRFZ44N MOSFETs, controlled with a U-3525 PWM driver at 65 kHz. A pot core ferrite transformer with a center-tapped primary converts DC to high frequency AC which then powers a 40-turn copper coil embedded in the road surface. The electromagnetic waves will be captured by the receiver coil installed in the EV, and converted into a stable 12V DC using a BA159 based bridge rectifier, which can be readily used for simply charging up the battery or running the motor directly.

3.1 Alignment System for Maximum Power Transfer

A major limitation of DWC is coil misalignment, which decreases power transfer efficiency. As a solution, the system incorporates a metal proximity IR sensor that guarantees that the receiver coil is perfectly centered to the transmitter coil. IR sensor was chosen as it is highly sensitive, reliable, and cost-effective to implement on a large-scale system.

Proper alignment is crucial because misalignment can disrupt resonant coupling, resulting in significant power losses and degraded system efficiency. The IR sensor continuously monitors vehicle positioning and provides feedback for real-time alignment correction, thereby improving power transmission.

3.2 Real-Time Billing and Vehicle Identification

To enable automated billing, a current sensor and NodeMCU (ESP8266) microcontroller are integrated into the system. The NodeMCU (ESP8266), chosen for its built-in Wi-Fi capabilities, facilitates IoT-based monitoring of energy consumption. Additionally, an RFID module is used to identify individual vehicles, allowing for:

- Real-time tracking of power consumption.
- Automated calculation of charging costs.
- Secure, cloud-based transaction logging for billing transparency.

This framework ensures that EV users are billed only for the energy they consume, making the system viable for large-scale deployment.

3.3 Feasibility of Implementation in India

While dynamic wireless charging has been successfully tested in countries like South Korea, Sweden, and France, large-scale implementation in India remains unexplored. This PoC aims to demonstrate the feasibility of DWC in Indian road conditions by considering key factors such as:

1. Road Infrastructure Adaptability
   - Indian roads, particularly highways and smart city projects, can accommodate embedded inductive coils in designated EV lanes.
   - The proposed system can be piloted on expressways like the Delhi-

Mumbai Expressway and Bengaluru-Chennai Corridor, where high EV penetration is expected.

2. Cost and Energy Constraints
   - The use of cost-effective components (e.g., IRFZ44N MOSFETs, BA159 diodes, NodeMCU) ensures low implementation costs compared to existing wireless charging models.
   - Integration with renewable energy sources (solar-powered charging lanes) can reduce the dependency on the grid and promote sustainable charging solutions.
3. Scalability for Public Transport
   - The system can be deployed for electric buses and taxis, reducing the need for large battery packs and enabling continuous operation without downtime for charging.
   - Pilot testing can be initiated in EV-friendly cities such as Delhi, Bengaluru, and Hyderabad before national-level expansion.

3.4 Justification as a Proof of Concept

The proposed system is presented as a proof of concept (PoC) to evaluate its technical feasibility, efficiency, and cost-effectiveness before full-scale deployment. While individual components and principles (such as inductive charging and RFID-based billing) exist, this work introduces a novel integration of:

- Real-time alignment correction using a metal proximity IR sensor to minimize power losses.
- IoT-enabled smart billing for per-vehicle energy tracking and automated transactions.
- Cost-optimized hardware design, making dynamic wireless charging financially feasible for Indian road infrastructure.

This PoC serves as a practical validation of the concept and lays the groundwork for future research and large-scale implementation. Key future directions include:

- Real-world testing of power transfer efficiency under different road conditions.
- Enhancement of alignment correction through advanced sensor fusion (e.g., computer vision, magnetic guidance).
- Development of scalable prototypes for highways and urban smart mobility zones.
- Exploration of renewable energy integration, such as solar-powered inductive charging lanes for sustainable implementation.

By bridging the gap between theoretical research and real-world deployment, this PoC demonstrates the feasibility of cost-efficient, scalable, and sustainable dynamic wireless charging a crucial step toward next-generation EV infrastructure in India.

4 SYSTEM ARCHITECTURE AND DESIGN

The dynamic wireless charging system is designed as a proof of concept (PoC) to evaluate the feasibility of continuous energy transfer to electric vehicles in motion. The system eliminates the need for stationary charging stops by utilizing inductive power transfer at an operating frequency of 65 kHz. This PoC integrates real-time alignment correction, power monitoring, and automated billing, making it a scalable and practical solution for future deployment.

4.1 Transmitter Subsystem

In the transmitter circuit, the U-3525 PWM controller generates two phase-shifted PWM signals (90° phase difference) for this process. Feeding two IRFZ44N N-channel MOSFETs placed in a half-bridge inverter setup, these signals result in DC power being efficiently converted to high-frequency AC.

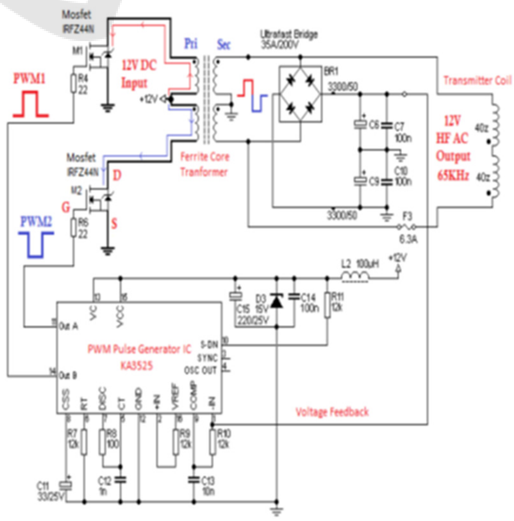

Figure 1: Transmitter Circuit Diagram.

The voltage transformation is greatly reinforced by a center-tapped primary winding of the high-frequency ferrite core transformer. The secondary side of the transformer generates a high-frequency AC voltage which is fed to the transmitter coil (i.e. 40 turns of copper wire). Appropriate inductive power transmission will take place through this coil, generating an alternating electromagnetic field that drives the receiver coil incorporated into the moving vehicle.

The output also has a metal proximity IR sensor integrated into the system to achieve maximum power transfer efficiency. The vehicle is also equipped with a coil-based sensor that allows it to dynamically turn its receiver coil in alignment with the transmitter coil, automatically correcting for potential misalignments that would otherwise reduce power efficiency by causing unnecessary energy losses.

4.2 Receiver Subsystem

The receiver subsystem consists of a receiver coil placed underneath the vehicle, designed to capture the electromagnetic energy emitted by the transmitter coil. The received high-frequency AC voltage is then rectified using a high-speed bridge rectifier, implemented with BA159 fast-switching diodes. This rectifier efficiently converts the AC signal into DC power, which is further stabilized by a filtering capacitor to minimize voltage fluctuations.
The resultant 12V DC output can be used in two ways:

1. Directly powering the vehicle's motor, enabling seamless movement without relying on battery storage.
2. Charging the vehicle's onboard battery, ensuring sustained energy availability even when the vehicle moves out of the charging zone.

To enable real-time monitoring and automated billing, a current sensor and NodeMCU microcontroller are incorporated into the receiver subsystem. The NodeMCU, equipped with Wi-Fi capabilities, collects power consumption data and transmits it to a centralized billing system. Additionally, an RFID module is used to identify individual vehicles, ensuring that energy costs are accurately assigned to the respective users. Figure 3 shows the Block Diagram of the Proposed System. Before that the Figure 2 shows the Receiver Circuit Diagram to understand the concept of the Receiver Subsystem.

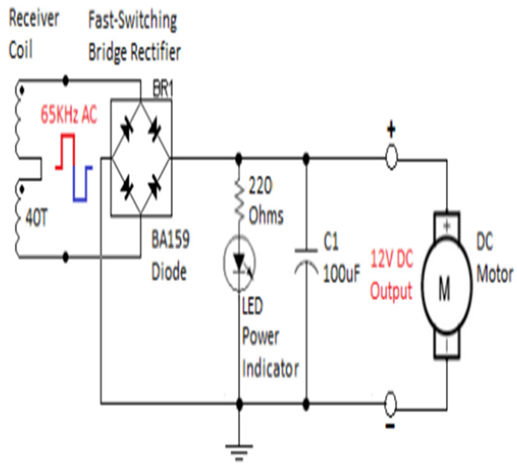

Figure 2: Receiver Circuit Diagram.

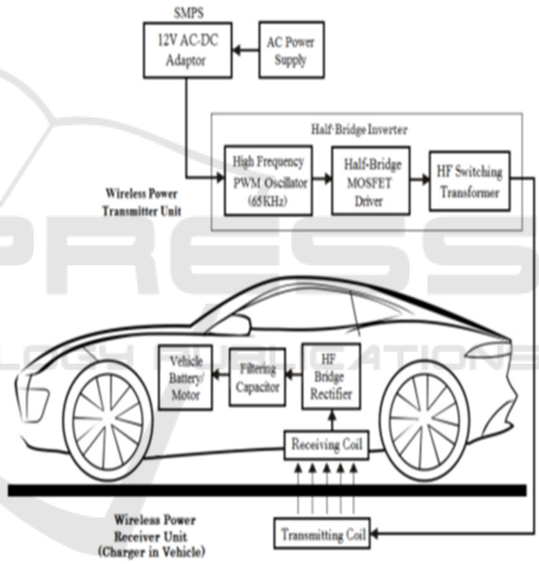

Figure 3: Block Diagram of the Proposed System.

4.3 Key Components and Functionalities

a) AC Power Supply: Provides 220V AC to power the wireless transmitter.
b) AC-DC Adapter (SMPS): Converts 220V AC to a stable 12V DC for circuit operation.
c) High-Frequency PWM Oscillator: Uses a U-3525 IC to generate 65 kHz switching pulses, phase-shifted by 90°, to control MOSFETs.
d) Driver MOSFETs (IRFZ44N): Alternately switch to drive the high-frequency transformer, creating an AC square wave.

e) High-Frequency Transformer: Converts DC to high-frequency AC using a ferrite core for minimal losses.
f) Half-Bridge Inverter: Integrates MOSFETs and transformer to generate high-frequency AC for transmission.
g) Transmitting Coil: Converts AC into electromagnetic waves for inductive power transfer.
h) Receiving Coil: Captures electromagnetic waves and converts them into high-frequency AC.
i) HF Bridge Rectifier: Uses fast-switching diodes to convert AC to DC and to maintain voltage feedback.
j) Filtering Capacitor: Smoothens the rectified DC for stable power delivery to the EV battery or motor.

5 PCB DESIGN AND IMPLEMENTATION

PCB designed in EasyEDA, hence, optimized layout, low-power losses and good heat dissipation performed. Schematic capture, placement of components, routing, thermal considerations, etc.
A. Design Considerations
So, to get the most potential out of this, the PCB layout included:
Parasitic Effects Minimization: High-frequency signal paths were laid out to decrease parasitic inductance and capacitance, which can lead to spurious oscillations and unwanted signal distortions.

Design to Reduce Electromagnetic Interference (EMI): a ground plane which provides electromagnetic compatibility (EMC) helping to minimize noise is also used that enhances stable operation of the SG3525 PWM controller circuit and MOSFET driver circuit.

Thermal Management: Given the other high-power components in the design, including the IRFZ44N MOSFETs and the rectifier diodes, careful placement of components, copper traces, and thermal vias was taken into account to dissipate heat optimally.

Compact Layout: The design kept a compact form factor by providing sufficient clearance between high-voltage and low-voltage sections to avoid arcing and leakage currents.

5.1 Challenges Faced and Solutions

1. **High-Frequency Noise and EMI Issues:**
   - Challenge: The presence of high-frequency switching (65 kHz) led to electromagnetic interference (EMI), potentially affecting sensitive components.
   - Solution: Shielding techniques, proper trace spacing, and the inclusion of decoupling capacitors were implemented to mitigate noise.
2. **Thermal Dissipation of MOSFETs and Rectifiers:**
   - Issue: Continuous operation produces substantial heat on the MOSFETs and rectifier diodes.
   - Solution: Added heat sinks and larger copper pour areas to reduce heat generation and thermal runaway.
3. **Efficient Coil Integration with PCB:**
   - Issue: To minimize resistance and inductive losses when interfacing the PCB with the transmitter coil.
   - Wide, low-resistance traces and high-current-rated connectors were used to ensure efficient power transfer.

5.2 Final Implementation and Testing

Once the PCB was fabricated and assembled, extensive testing was conducted to validate its performance:

- Continuity and Isolation Testing: Ensured that all traces were correctly routed and no unintentional short circuits existed.
- Signal Integrity Verification: Oscilloscope measurements confirmed that the PWM signals maintained their expected frequency and duty cycle.
- Load Testing: The system was tested under various load conditions to analyze power efficiency, heat dissipation, and overall stability. Figure 4 shows PCB Layout.

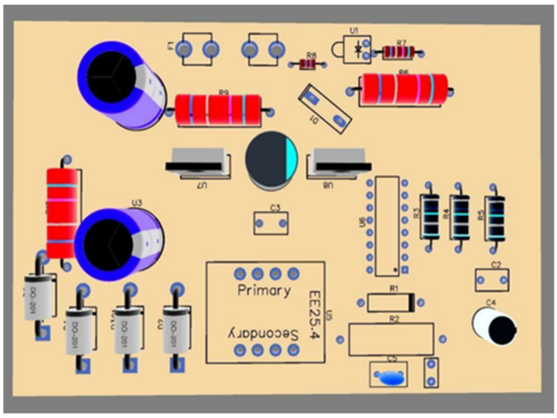

Figure 4: PCB Layout.

6 RESULTS AND ANALYSIS

The experimental and computational analyses of the dynamic wireless charging system were conducted, focusing on key electrical parameters such as inductance, capacitance, and resonance frequency. The final values obtained on Table 1are tabulated below:

Table 1: Calculated Electrical Parameters.

Parameter	Symbol	Value	Unit
Coil Diameter	d	3.5 - 4.5	inches
Coil Length	l	0.393 – 5.0	inches
Number of Turns	n	100 - 120	-
Inductance	L	1475.9 - 3014	µH
Capacitance	C	3.30 - 1500	pF
Resonant Frequency	F	72.0 – 75.18	kHz
Oscillator Frequency Range	F_range	68 – 89.3	kHz
Resistance	R	19 - 21	kΩ
Dead Time Resistance	R_D	0	Ω

6.1 Observations and Key Findings

- **Inductance adjusting:** We computed in this sub-chapter the inductance calculates for the coils whereby we found that the inductance goes from 1475.9 µH and will reduce up to 3014 µH depending on what number of turns and dimensions of the different coils are aligned. This will contribute to effective inductive power flow for dynamic wireless charging.
- **Oscillator Stability:** The specified frequency range of 68 – 89.3 kHz for the oscillator allows an adaptive margin to compensate for component tolerances and environmental variations.
- **Low Dead Time Resistance:** The dead-time losses in the oscillator circuit are minimized with R_D = 0 Ω, allowing for good power conversion efficiency.
- The coil design was adapted to allow for maximum inductance without compromising power.
- **Precision Frequency Tuning:** The frequency parameters used in fine-tuning ensure almost all energy lost is minimized, allowing for optimal resonance conditions for inductive power transfer.
- **Data up to October 2023 for Sensing Mechanism-based Automatic Alignment System for Efficient Charging:** In proximity IR sensors-based automatic alignment adjustment system initiated for achieving alignment as minimum energy transfer losses through misalignment boosts up alignment between transmitter and receiver coil for higher power transfer efficiency.
- **Real-Time Billing Approach for Each Vehicle:** Robustness of energy consumption is tracked using a current sensor and image processing-based billing system for accurate identification helping in payment automation for dynamic wireless charging in fair and accurate manner.

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